Significance of Embodied Energy as a Measure of Sustainable Construction

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Abstract

Total energy consumption of a domestic building, which has a direct impact on its carbon foot print, is a combination of, both, embodied energy and operational energy. Although enough emphasis has been given to the conservation of operational energy component there seems only little attention has been given to the estimation of embodied energy component. For example, in Australian domestic industry, it would take about 30 years of operational energy consumption to break-even with the embodied energy of the building at the time of occupancy. Considering that current domestic building stock generally having 50 years life expectancy, that amounts to, approximately, one third of the total energy consumed by a domestic building during its life cycle. Ability to account for embodied energy consumption in building materials and construction processes, accurately, has therefore became a priority research area during last decade. This paper presents research outcomes of embodied energy of domestic buildings, in Australian context, currently underway at the RMIT University. This paper, which is an outcome of the research in to the embodied energy component of such buildings, discusses the current practices of domestic construction, and strategies to estimate and minimise the embodied energy component of domestic building construction. The major outcome of this research is to provide tools for the designers, developers and owners to optimise embodied energy within budgetary constraints.

Keywords: domestic construction; embodied energy; sustainability

1. Introduction

The growth in domestic building construction is used as an indicator as well as a controller of the economic growth in developed economies. For instant, the interest rates on housing loans are quite effective in accelerating or decelerating, respectively, an underperforming or over heating economic cycle. This is, therefore, a sector where message of sustainability can be quite effectively disseminated to the general public. In Australia, over the last decade, the government has been very proactive in improving community awareness in this sector. Significant improvements in the way public perceive the extra cost of sustainability aspects of this growing industry has been evident, and a greater emphasis is now given to its environmental duty. Environmental objectives associated with the planning, selection of materials, construction, and operation of domestic buildings to meet environmental quality has been currently going through a policy innovation cycle. Domestic buildings can broadly categorise and study in three categories, based on the type of occupancy. They are, single dwellings, medium density, and high density construction. Although these definitions are quite fluid and relative in nature, from region to region, in Australia it varies from a single dwelling per title to many hundreds of units per single title. In terms of energy efficiency of usage and energy intensity of construction it may be prudent to define per unit area or per capita for meaningful comparisons.

Total energy consumption of a domestic building, which has a direct impact on its carbon foot print, is a combination of, both, embodied energy (energy intensity) and operational energy (energy efficiency). Although enough emphasis has been given to the conservation of operational energy component there seems only little attention has been given to the estimation of embodied energy component. Figure 1 demonstrates that, in Australian domestic industry, it would take 30 years on average, for operational energy consumption to break-even with the embodied energy of the building since the time of occupancy. Considering that current domestic building stock on average having 50years life expectancy, that amounts to, approximately, one third of the total energy consumed (sum of both embodied and operational energy) by a domestic building during its life cycle would comprise of embodied energy.

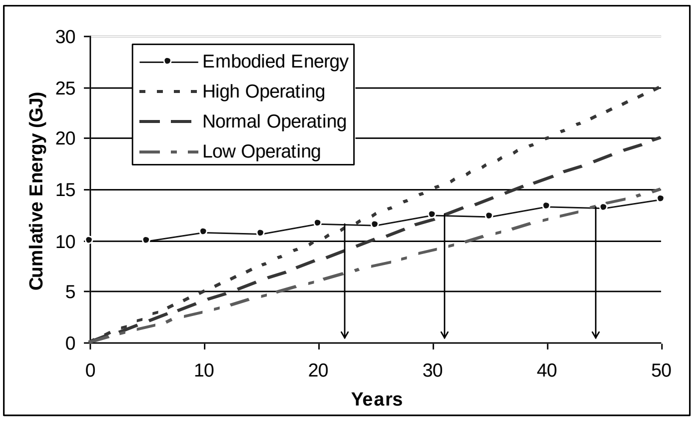

Figure 1: Relationship between Embodied Energy and Operational Energy (source: CSIRO-2004)

The problem of environmental impact due to the growing demand for housing is unavoidable. However the process can be engineered, and managed to minimise the impact (Ken, 2002). Embodied energy, as mentioned before, is a measure of environmental impact, which can be quantified and optimised through proper selection of materials and construction processes during the planning stage. Embodied energy is defined here as the cumulative energy embedded in the process of bringing a domestic unit into being. This includes the energy embedded in the processing and manufacturing of materials, transporting and handling, engineering, and construction practices []. More research work is needed to include energy embodied in common building products and construction processes, and practices which are different for different regions of the world. This paper represents the Australian building practices and does not include the associated administrative, financing, and embodied energy of residing in amnesties.

As mentioned, efficiency in operational energy consumption (after occupation) is well adapted by the domestic building industry in Australia (Thormark, 2002). For example, in Australia five-star energy rating is a mandatory requirement for new domestic constructions since 2006 and many leading builders have already taken steps to upgrade their practices to position themselves favourably in the market and currently capable achieving eight-star rating quire easily (de Silva, 2010).

The current evaluation of star-rating does not include the energy intensity of the construction materials or define any upper limits/ceilings for a house. Not having such controls for embodied energy would become untenable, in a long run, with the market driven upward by extravagant living expectations with higher per capita embodied energy component. For example, floor area per capita has quadrupled over the last 30 years and the furniture, cars, white goods, consumables and appliances use within an average house hold has sophistication unforeseen. So, if these are taken into consideration, cumulative embodied energy of a house hold could well exceed the operational energy. That leads us to acknowledge that, in sustainable living practices, auditing of embodied of house holds should not go undetected.

Optimisation of energy embodied in the construction phase is possible, through the selection of low energy construction materials, smart engineering, building technologies, and practices which are distinctly different in the three sectors mentioned above. This paper will contribute to improve understanding of the complex problem of embodied energy in typical Australian housing developments using single dwelling as an example and also introduced the reader to the preparation of a “Bill of Embodied Energy” (BEE) similar to preparing a BOQ in any development.

2. Proposed Embodied Energy Assessment Tool

This section presents the developed and tested web based embodied energy estimation software as a decision support tool, which estimates and produces a Bill of Embodied Energy (**BEE**) in a manner similar to a standard building cost guide help to produce a Bill of Quantities. The proposed tool, which is named as BEE, can be used to estimate embodied energy of domestic buildings. In this standardised format, the user can use estimate the embodied energy for listed bill of construction processes and activities, such as floor, roof, and external wall construction etc. BEE tool has a cost data-base which also enables it to estimate the cost of the construction for comparison. The methodology is illustrated through a flow chart as is given in Figure 2. As mentioned, the proposed concept is named as the “Bill of Embodied Energy (BEE)” similar to a “Bill of Quantities (BOQ)” which is much familiar in the construction industry. Policy makers and regulators would, in future, consider establishing limitation of embodied energy which can then be used as a control mechanism to achieve a sustainable domestic building industry. The out comes also highlight processes with has higher embodied energy intensity, thus prompting such industries to move toward a more carbon neutral process in a way of improving their manufacturing processes, transportation and double handing on site.

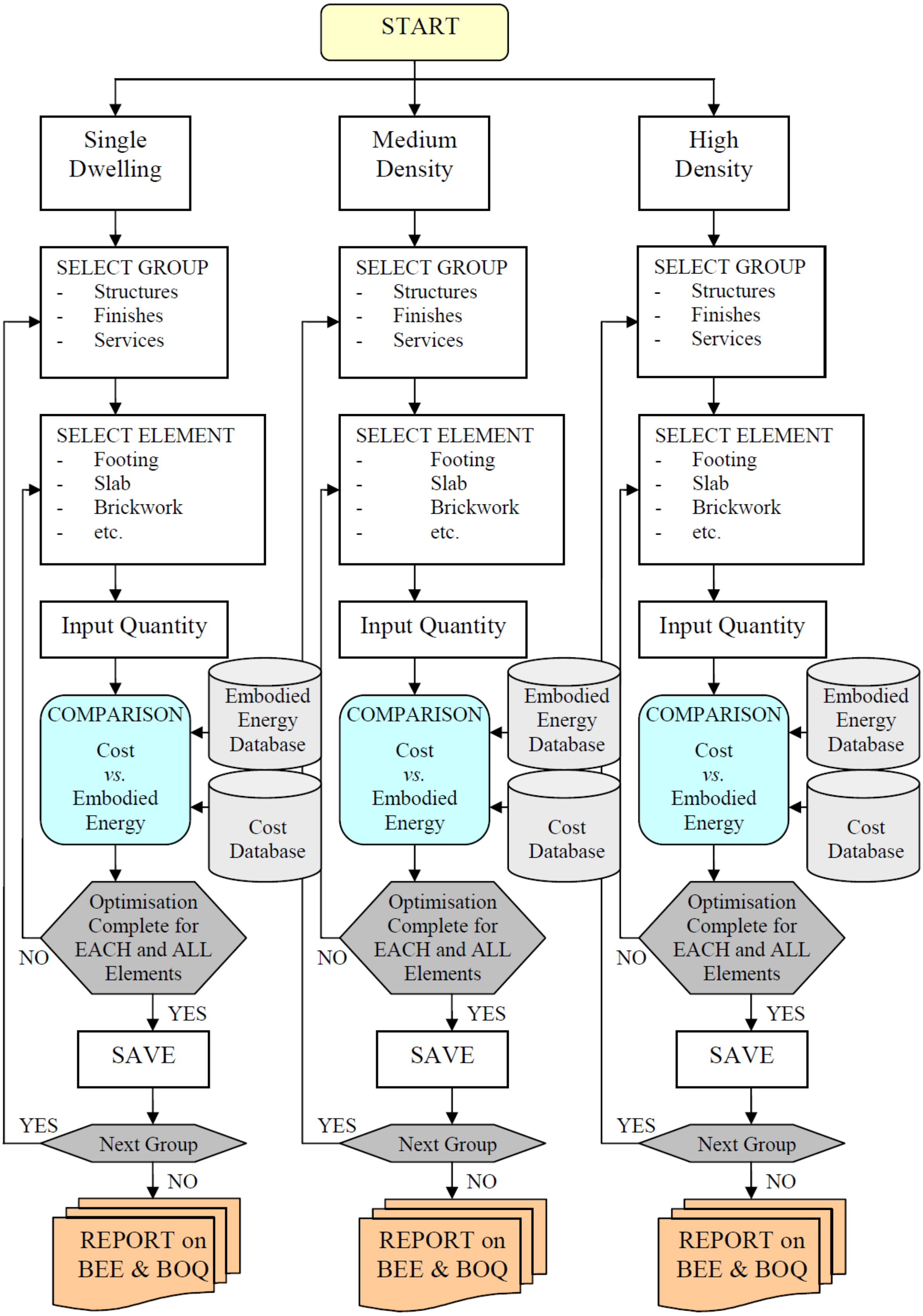
START
Single Dwelling
Medium Density
High Density
SELECT GROUP
- Structures
- Finishes
- Services
SELECT ELEMENT
- Footing
- Slab
- Brickwork
- etc.
Input Quantity
Embodied Energy Database
Cost Database
COMPARISON
Cost vs. Embodied Energy
Optimisation Complete for EACH and ALL Elements
NO
YES
SAVE
Next Group
YES
NO
REPORT on BEE & BOQ

Figure 2: BEE Methodology Flowchart

The main objective of this research development is to provide sufficient and easy-to-use data to evaluate quantities of embodied energy for standard activities of domestic building construction. By doing so, it is envisaged in emphasising that the preparation of a bill of embodied energy is equally important in preparing a bill of quantities for a given project situation. Similar to the decision makers and the clients in a traditional setting would scrutinise the project cost of their development project, in future planners and environmental policy frameworks must scrutinise the building industry's energy intensity in construction through embodied energy.

3. Current Practices and Application of BEE

BEE software was calibrated using established research data and comparison of case studies conducted by others (Treloar et.al, 2001). Following is a brief introduction to the current domestic building industry practices and their typical distribution of embodied energy. In order to have some meaningful comparisons researchers determine the embodied energy of a given building by adding the total embodied energy of the products, and expressing it as embodied energy per unit area of each housing unit (Treloar, 2001). Through this research, we have demonstrated that measure alone is not sufficient. One major proposal was to suggest that the embodied energy of a domestic building is best described, as a measure, by GJ/occupant. This argument was based on the fact that the house hold embodied energy per occupant rises at much higher rate than that of the embodied energy per unit area of the house. In other words, there seems an upward trend, where life-style needs demands larger homes for fewer occupants. Most new Australian single dwellings, for example, average 80 square meters per person. Embodied energy, obviously, depends on methods and materials of construction. Figure 1 shows the composition of the embodied energy of a typical brick veneer, timber framed single dwelling in Australia (Siu, 2006).

It is evident that high volume items such as external walls, internal walls and roof have greater impact on the end outcome and therefore the optimisation should be focused on such high intensity, high volume sectors. Figure 3 also includes embodied energy values for plumbing, electrical, kitchen joinery, and other fixtures which are relatively low.

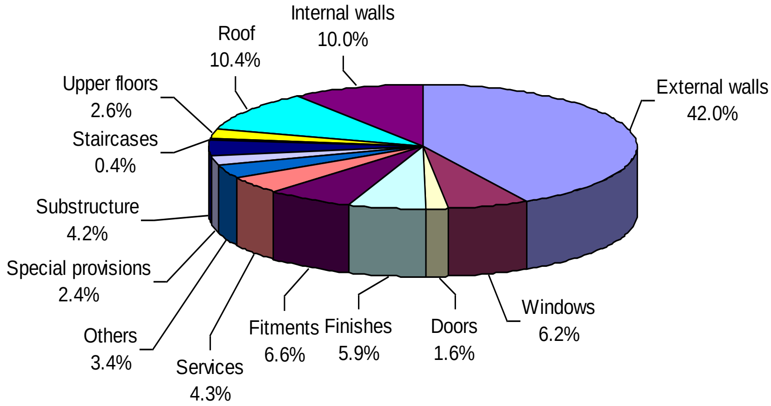

Figure 3: Distribution of Embodied Energy of a Typical Australian Home

Table 1 provides an inventory of commonly used building materials and structural elements used in the Australian industry. Selected listing covers only the high embodied energy items identified in Figure 3.

Table 1: Typical structural materials/systems used in Australian domestic building stock

	Single Dwelling	***Medium Density***	***High Density***
Foundations	*Concrete Slab on Ground*	*Concrete Slab on Ground*	*Raft foundations + Concrete*
Upper Floors	*Particle boards on timber joists/beams*	*Composite floor systems OR R/C slabs*	*Composite floor systems OR R/C slabs*
External Walls	*Brick façade, load bearing timber frames with internal plaster boards OR Brick façade, load bearing steel frames with plaster boards*	*Load bearing tilt-up concrete panels OR Brick or cement block infilled, load bearing steel or R/C frames*	*Glass Façades with Aluminium frames, load bearing R/C or steel frames OR Tilt-up panels with load bearing R/C or steel frames*
Internal Walls	*Timber framed plaster boards*	*Timber framed plaster boards*	*Timber framed plaster boards*
	OR Steel framed plaster boards	*OR Steel framed plaster boards*	*OR Steel framed plaster boards*
Roof	*Concrete tiles*	*Water proof R/C concrete slabs OR Colorbond steel*	*Water proof R/C concrete slabs*
	OR Colorbond steel		

Structural Frames	*Timber OR Light steel*	*R/C OR Structural steel*	*R/C OR Structural steel*

There were number of challenges encountered in acquisition of quality data and developing the embodied energy databases for BEE software tool as well as aligning the BEE to a standard BOQ. These have been identified as gaps needing attention during the early stages of the research. Significant time and effort in this research was directed towards resolving these issues. For completeness of the paper and also for the benefit of the future researchers in this area the most challenging and time consuming two aspects are given here.

1. Basic embodied energy data available are limited, fuzzy and regionally sensitive. For example, the embodied energy of sourcing basic materials such as fine/course aggregates, cement and water depends on the region. Processing, transportation and handling also significantly different from one application to another. So the general descriptors - "embodied energy of concrete" - must be taken with due care.

2. Basic embodied energy data is normally available as the energy embedded in raw materials – steel, concrete, timber. It does not necessarily discriminate reinforced concrete vs. concrete or reinforcing steel vs. structural steel. On the other hand the standard cost guides or schedule of rates used in engineering applications (Rawlinson, 2006, CORDELL, 2006], descriptors are well defined and the cost breakdown indicates details of each step. For example cost guides would describe a strip footing as "600mm deep x 300mm wide strip footing with F12TM4 reinforcement mesh" with no ambiguity.

This research project addressed this issue quite effectively, in developing BEE software tool, by establishing a database, which is compatible with the standard cost guides such as Rawlinson's handbook and Cordell cost guide, which are widely known by the Australian industry. During this research one other important aspect authors have encountered was that some industries quite uncomfortable in divulging processing details and energy sensitivity of their product. Mumma (1995) has noted that very few companies have embodied energy data available in a form, which could facilitate the deduction of energy coefficients efficiently. Even fewer had done calculations to establish the amount of energy they were using to produce their total output or individual products, which is a challenge this area of research confronts regularly. However in future, especially when carbon auditing becomes mandatory, the situation may improve for good.

BEE

No	Element		Detail	Uni t	Qt y	Cost ($)	Embodied Energy (GJ)
1	Concrete In-Situ	Slab Concrete	Pump	m3	14	2752.54	2.46
2	Mansory - Brickwork	Clay Brickwork	Walls 230mm thick	m2	254	36388.0 4	587.85
3	Carpentry	Roof Truss	9000mm span @600mm centres	m2	180	6274.8	32.95
4	Mansory - Brickwork	Aluminium Core Bitumen Coated (0.45mm)	230mm wide	m	135	433.35	7.11
5	Roofing	Concrete Tile Roofing	Round edge pattern	m2	160	5760	208.00
TOTAL COST							**$ 51608.73**
TOTAL EMBODIED ENERGY							**838.39 GJ**

Figure 4: Indicative BEE report out-put (truncated for illustration)

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